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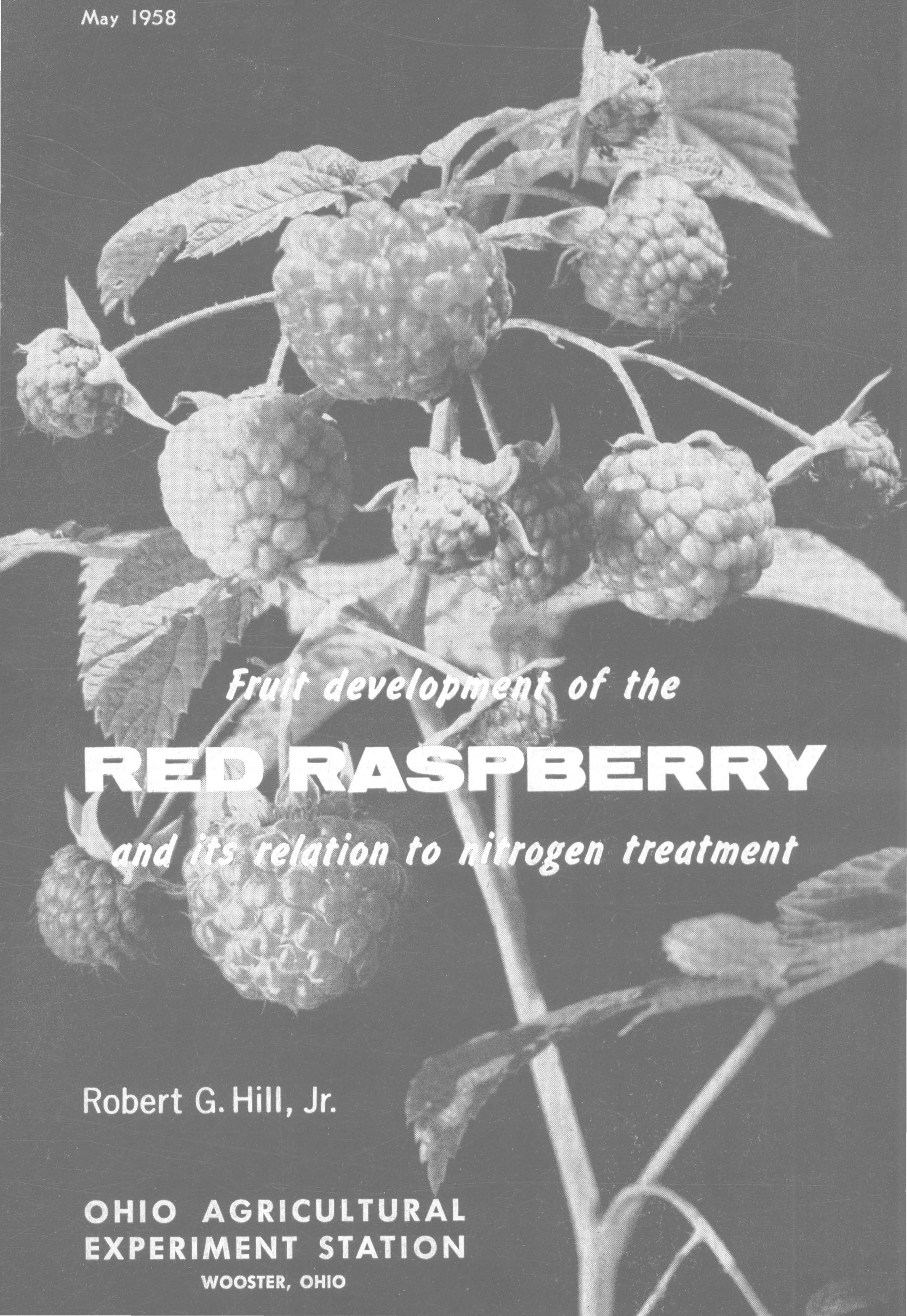

Fruit development of the

RED RASPBERRY

and its relation to nitrogen treatment

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FRUIT DEVELOPMENT OF THE RASPBERRY AND ITS RELATION TO NITROGEN TREATMENT

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A number of reports have been published on the physical, chemical and anatomical changes which occur during the development of the fruits of various tree and small fruit crops. The effect of certain environmental factors upon the development of these fruits has also been considered. Although the factors which affect the growth and yield of the red raspberry, Rubus strigosus and R. strigosus hybrids have been studied, only limited attention has been given to changes which occur during the development of red raspberry fruits.

Recently, work has been published (10 & 11) upon the histogenesis of the endocarp, outer epidermis, parenchyma, and receptacle tissues of red raspberry fruits. No detailed work has been published, however, on the development of these fruits. This paper is a report of a study designed to ascertain certain physical and chemical changes which take place during the development of these aggregate fruits and to determine what effect differential nitrogen fertilization might have upon those changes.

LITERATURE REVIEW

The gross morphological changes that take place during the development of the various drupaceous fruits have been extensively studied. The development of the peach fruit has received the most attention. An extensive review of these studies has been published (8). Morphological changes occurring during the development of the plum (6), cherry (7), olive (2) and apricot (4) have also been studied. These drupaceous fruits all develop similarly. The development of fruits of this group is characterized by three marked growth stages. The first stage, initiated at the time of full bloom, is one of rapid growth. The second stage is one of reduced growth and the third, which ends at maturity, is one of rapid growth. It is generally accepted (8) that the first stage is associated with a period of cell division, the second with the development of the embryo and the hardened endocarp, while the third stage is one of cell enlargement. The duration of the various stages varies primarily with the time which elapses between full bloom and maturity of the various kinds and varieties of stone fruits.

The gross morphological development of the pome fruits from full bloom to time of maturity has also been studied. Work with the pear (9) has shown that the development of this fruit follows a definite sequence. Its development is similar to that of the drupe fruits. There is a period, which commences one week after full bloom, of very rapid growth, followed eight weeks later by a period of reduced growth rates. This period of two weeks duration is followed by a period of accelerated growth until maturity. Mitchell (9) in his work associated the second stage of growth with the development of the embryo.

An excellent review of literature dealing with changes in the hydrogen ion concentration and the titratable acids content in developing fruits was made by Caldwell (1). He summarized a number of papers dealing with these changes in a large number of fruits as follows: "These data collectively indicate that both active (dissociated) and total titratable acidity increase as growth advances, attain a maximum about the time ripening begins, and decrease as ripening proceeds". He studied (1) in a detailed manner these changes in ripening apples, cherries, strawberries and other fruits as well as in a general way these changes in raspberries and blackberries. His results substantiated this statement. In general, as these fruits developed the hydrogen ion concentration increased as did the titratable acid content to a maximum value and then decreased as maturity advanced. At the conclusion of his paper (1) Caldwell presented an interesting working hypothesis as to the relationship of the hydrogen ion content of the fruit and the development of that fruit; "namely, that variations in water absorption by the hydrophilic colloids of the young fruit, caused by changes in hydrion concentration of the tissue fluids may be a factor of prime importance in determining the form and shape of the growth curve of the fruit".

Some work has been published (8) upon the effect of differential nitrogen fertilization upon the development of the peach. For this work comparable six-year-old Halehaven trees maintained under cultivation and cover crops were used. One tree was unfertilized while one was given two five-pound applications of nitrate of soda. One application was made in late March, the other in early June. The results of this study showed that the rate of development of the fruits produced by the different trees was almost parallel regardless of the index of growth considered, until three weeks before harvest, when the fruit from the non-treated tree developed more rapidly and then was surpassed by the fruit of the nitrogen fertilized tree. The fruits produced by the fertilized trees were six days later in maturity and were of greater size. It was found that the ratio of flesh to stone of these later maturing fruits was greater on either a fresh or a dry weight basis. In interpreting these results it is important to note that the fertilized tree received a total of ten pounds of the 16.0 percent nitrogen carrier, an excessive applica-ion for such a six-year-old tree. It is often recommended that such trees be given 0.25-0.33 pounds of a 16.0 percent nitrogen carrier, or its equivalent per year of tree age. If the tree had been fertilized accordingly it would have received 1.50 or 1.98 pounds of nitrate of soda. Thus comparison was made between peach fruits produced on a tree that received no nitrogen fertilizer and on one that received more than five times as much nitrogen fertilizer as is normally recommended for commercially grown trees.

MATERIALS AND METHODS

These studies were conducted at Wooster, Ohio, during the 1952 growing season. Fruits for the study were obtained from a well-established four-year-old Latham red raspberry planting which was used primarily for a comparison of different cultural practices. All fruit samples were collected from plots which were maintained under the same soil management practice, cultivation with cover crops of rye and soybeans. Samples were obtained from a total of twelve thirty-foot plots located at random within the planting. Four of the plots were unfertilized (0 N), while four were fertilized with nitrogen at the rate of fifty pounds of actual nitrogen per acre (50 N), and the remaining four were fertilized with nitrogen at the rate of one hundred pounds of actual nitrogen per acre (100 N). Ammonium nitrate or ammonium sulfate were the nitrogen carriers used. The fertilizer treatments had been applied for three years and were applied in 1952 on April 17. In all plots the canes were headed at 54 inches and were supported by a wire trellis.

The terminal flowers of the fruiting clusters reached the "balloon" stage on June 8th at which time approximately one hundred and seventy-five flowers were selected for study in each of the twelve plots. All of the selected flowers were tagged for future identification. All of the flowers selected were in the terminal position of the flowering cluster.

At the time of full bloom, June 9, 1952, five representative tagged flowers were collected within each test plot; a total of twenty representative flowers from plants growing under each nitrogen level. The samples from each treatment were composited. As soon as the flowers were harvested they were taken to the laboratory where after removing the calyx, peduncle, stamens, and perianth, the basal diameter, polar diameter, and weight of each of the developing young fruits was determined. Following these determinations the developing fruits from each fertilizer treatment were grouped and their volume was determined by water displacement. The hydrogen ion concentration for each lot, after blending with water, was determined with a Beckman pH meter. Finally, the total acid content was determined by titrating with approximately 0.1N NaOH to a pH of 7.0. The total acid values were converted to percent citric acid.

At two-day intervals from the time of full bloom until maturity, July 11, 1952, twenty representative tagged developing fruits from each of the fertilizer treatments were taken to the laboratory where they were handled in the same manner as indicated above. By the fourth day after full bloom the berries were of sufficient size that they could be separated into carpel and receptacle tissues. On that sampling date, and on each succeeding sampling date, the weight, volume, and length of the receptacle, as well as the weight and volume of the carpel tissue, were determined. From the time the berries had reached sufficient size that individual drupelets could be separated, twelve days after full bloom until just prior to maturity, measurements of the length, diameter, and weight of the individual drupelets were made. For these studies the terminal drupelets of each of the sampled berries was used. The effect of the differential nitrogen treatment upon the different growth indices was compared at each sampling date whenever possible by a one-way analysis of variance.

Rainfall records were maintained throughout the season of fruit development. Shortly after the harvest season, July 28, 1952, leaf samples were collected from the various plots. These samples were used to determine the effect of differential nitrogen treatment upon leaf color, leaf area and the total nitrogen content of the leaf. Leaf area was determined by means of an area photometer, while relative leaf color was determined by a reflectometer and leaf nitrogen by the Kjeldahl method.

RESULTS

The aggregate fruits of the Latham red raspberry matured 32 days after full bloom. There was a great similarity between the development of these fruits and fruits of the drupe class.

MORPHOLOGICAL DEVELOPMENT IN THE BERRY

The discussion of the morphological development of the red raspberry is based upon the mean value obtained from measurements of berries produced by plants under all three nitrogen treatments. The morphological development of this fruit is shown in Figure 1, by representative berries collected at two-day intervals from time of full bloom until maturity. The effect of nitrogen fertilization upon berry development will be considered in another section of this paper.

Basal and Polar Diameter—The development of the berry, as indicated by the changes in basal and polar diameter, followed the typical growth pattern which has been reported for a number of other fruits. When this growth, Table 1, was plotted, Figure 2, typical sigmoid curves were obtained. There were three marked stages in this development. The first phase of very rapid growth occurred from the time of full bloom until the 10th day after bloom. During this stage the mean increase in polar diameter was 4.3 mm. while in basal diameter it was 5.4 mm., an increase of 138.7 percent and 180.0 percent respectively.

The second stage of growth was characterized by a marked reduction in rate of growth. This period occurred from the 10th through 20th days. During this second stage there was almost no change in the size of the fruit. During this entire ten-day period the average increase in both polar and basal diameter of the berry was 0.3 mm.

The third stage of development was a period of accelerated growth. It encompassed the period from the 20th day after full bloom through the time of maturity, 32 days after full bloom. During this period, the greatest actual average increase in size occurred. The average daily increase in polar diameter was 0.56 mm. while increase in basal diameter was 0.63 mm. During this period the increase in these measurements amounted to 48.5 and 54.2 percent respectively for the polar and basal diameters. It should be noted that there was little increase in either diameter between the 30th and 32nd day after full bloom.

It was found that during its development the berry grew more in basal than polar diameter. From the time of full bloom until maturity the berry increased 443 percent in basal diameter while the increase in polar diameter during that period was 400 percent.

Weight of Berry—When the data concerned with the weight increases that occurred during the development of the berry, Table 1 and Figure 3, were examined, the typical growth curve reported in the development of drupe type fruits was noted. The three marked stages of growth were clearly defined.

During the first stage of growth the mean weight increased rapidly from 0.024 grams to 0.256 grams in 10 days, an average daily increase of 0.023 grams. During Stage II the total increase in weight was only 0.060 grams. In the final phase of growth, Stage III, a marked acceleration in growth occurred. During this period the weight increased

TABLE 1.—Changes in the average basal diameter, polar diameter, weight, volume, pH, hydrogen ion, and total acid content recorded at two-day intervals from full bloom, June 9 to time of maturity, July 11, of fruits of the Latham red raspberry. Wooster, Ohio, 1952

Days from full bloom	Basal diameter (mm.)	Polar diameter (mm.)	Weight (gms.)	Volume (ml.)	pH*	Concentration hydrogen ion	Percent citric acid
0	3.0	3.1	0.024	0.029	6.17	0.00000068	0.28
2	4.0	3.9	0.042	0.043	5.71	0.00000193	0.43
4	5.4	4.9	0.084	0.069	5.82	0.00000153	0.48
6	6.0	5.3	0.119	0.102	5.70	0.00000200	0.54
8	8.0	6.8	0.223	0.201	5.68	0.00000207	0.36
10	8.4	7.4	0.256	0.240	5.25	0.00000556	0.48
12	8.3	7.2	0.236	0.233	4.99	0.00001033	0.48
14	8.4	7.2	0.246	0.237	4.79	0.00001633	0.57
16	8.6	7.5	0.303	0.293	4.59	0.00002633	0.70
18	8.5	7.3	0.291	0.263	4.51	0.00003066	0.71
20	8.7	7.7	0.316	0.287	4.53	0.00002933	0.68
22	9.4	8.2	0.405	0.373	4.10	0.00007900	1.11
24	10.2	8.9	0.506	0.473	3.69	0.00020333	1.35
26	12.9	11.2	0.996	0.956	3.36	0.00044000	1.42
28	14.1	12.7	1.329	1.275	3.23	0.00058333	1.33
30	16.0	14.2	1.924	1.838	3.50	0.00032000	1.06
32	16.3	14.5	2.138	2.019	3.50	0.00032000	0.99

*Obtained by converting pH values to Hydrogen ion values, determining the mean and converting back to pH.

from 0.316 to 2.138 grams, an average daily increase of 0.152 grams. Thus, during the first phase the weight increased 966 percent while during the second and third phases the weight increased 13.7 and 634 percent respectively. It should be noted that the rate of growth diminished between the 30th and 32nd day after full bloom.

The increase in berry weight was not a simple function of increased volume. The berries were found to have increased 8,808 percent in weight while the volume increased 6,862 percent during the 32 day developmental period.

Berry Volume—The growth of the red raspberry fruit as determined by changes in volume from the time of full bloom to maturity, Table 1 and Figure 4, paralleled the concurrent changes in weight, basal diameter, and polar diameter already discussed. Again the three definite stages of growth were apparent.

At the time of full bloom the average volume of the fruits was 0.029 ml. At the conclusion of the first stage of growth the berry had increased in volume to 0.240 ml. Thus during the first phase of growth the volume of the berry had increased 727 percent. During the 10-day period the average daily increase in volume was only 0.022 ml. During the second growth period the berries grew very little from 0.240

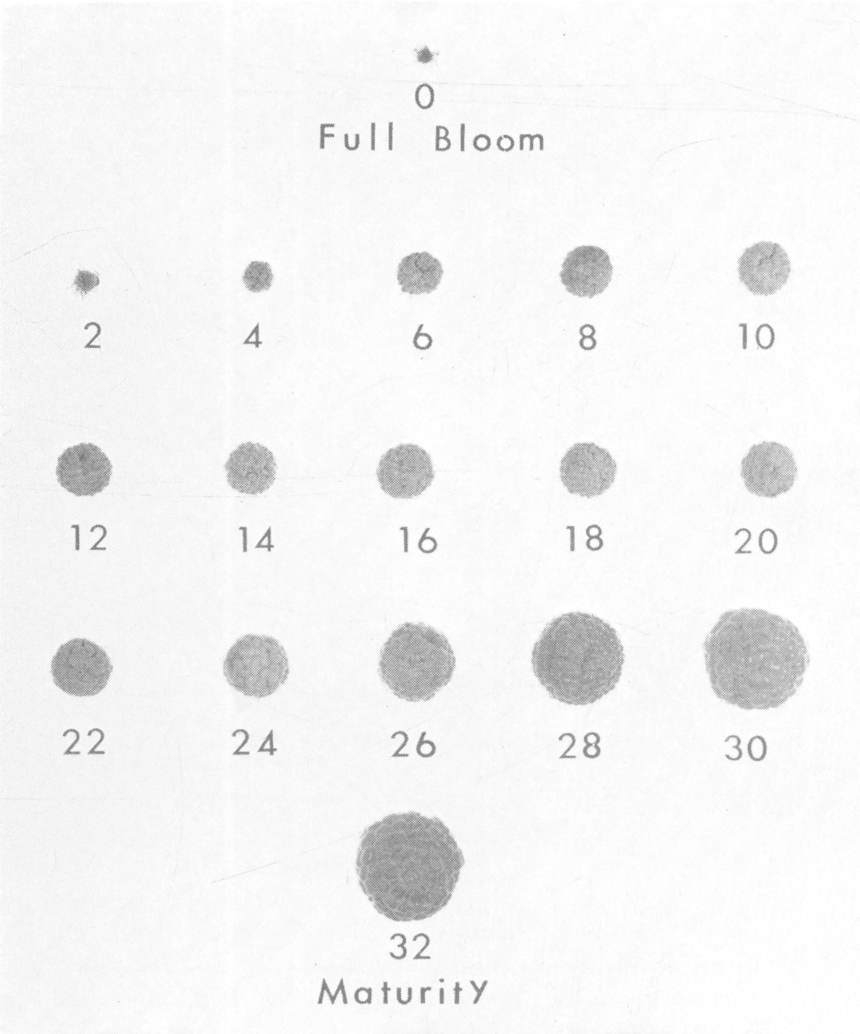

Fig. 1.—Representative Latham red raspberry fruits collected at two-day intervals showing the development of the fruit from the time of full bloom to maturity.

ml. to 0.287 ml., an increase during the 10-day period of only 9.6 percent. On an average daily increase basis the berries grew 0.0047 ml. During Stage III growth was again markedly accelerated. The average volume increased from 0.287 ml. to 2.019 ml., an increase of 667 percent. The average daily increase in volume during this period was 0.144 ml.

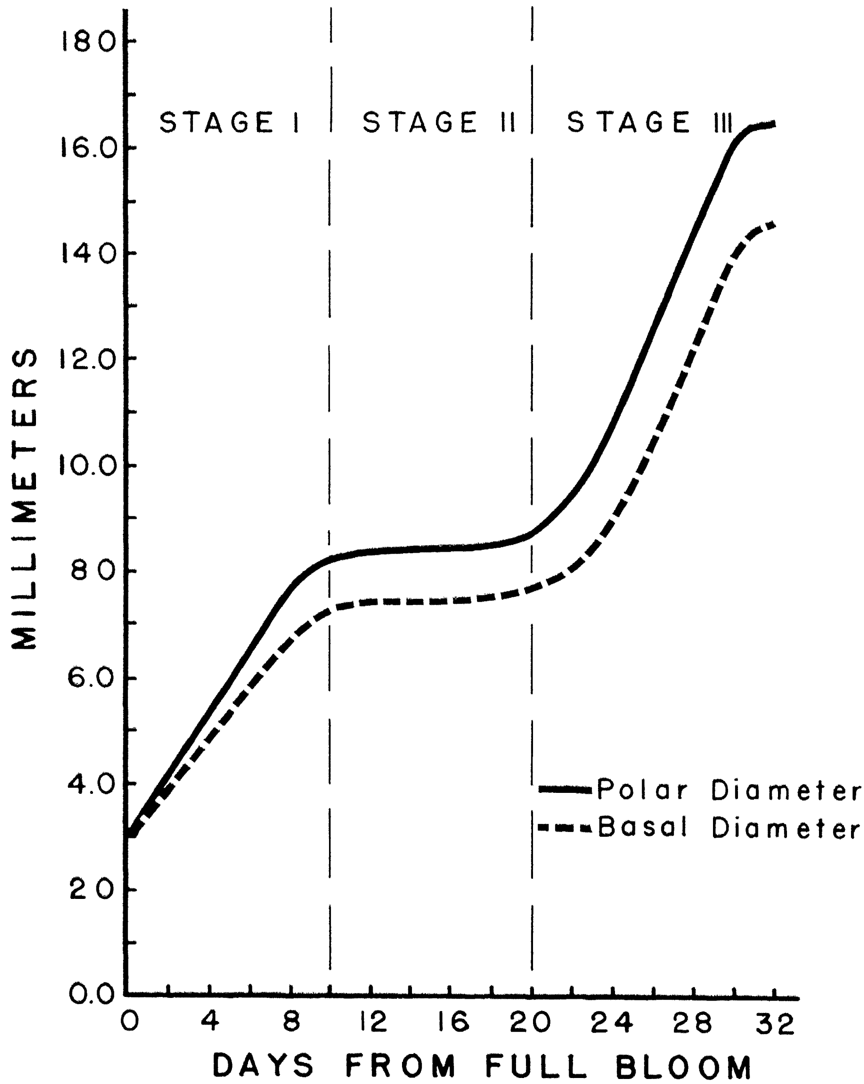

Fig. 2.—Changes in polar and basal diameter recorded at two-day intervals from full bloom, June 9, to maturity, July 11, of Latham red raspberry fruits. Wooster, Ohio. 1952.

Hydrogen Ion—The hydrogen ion concentrations of the fruit was lowest at the time of full bloom, pH 6.18. As the fruits matured the hydrogen ion concentration increased in a rather uniform manner until

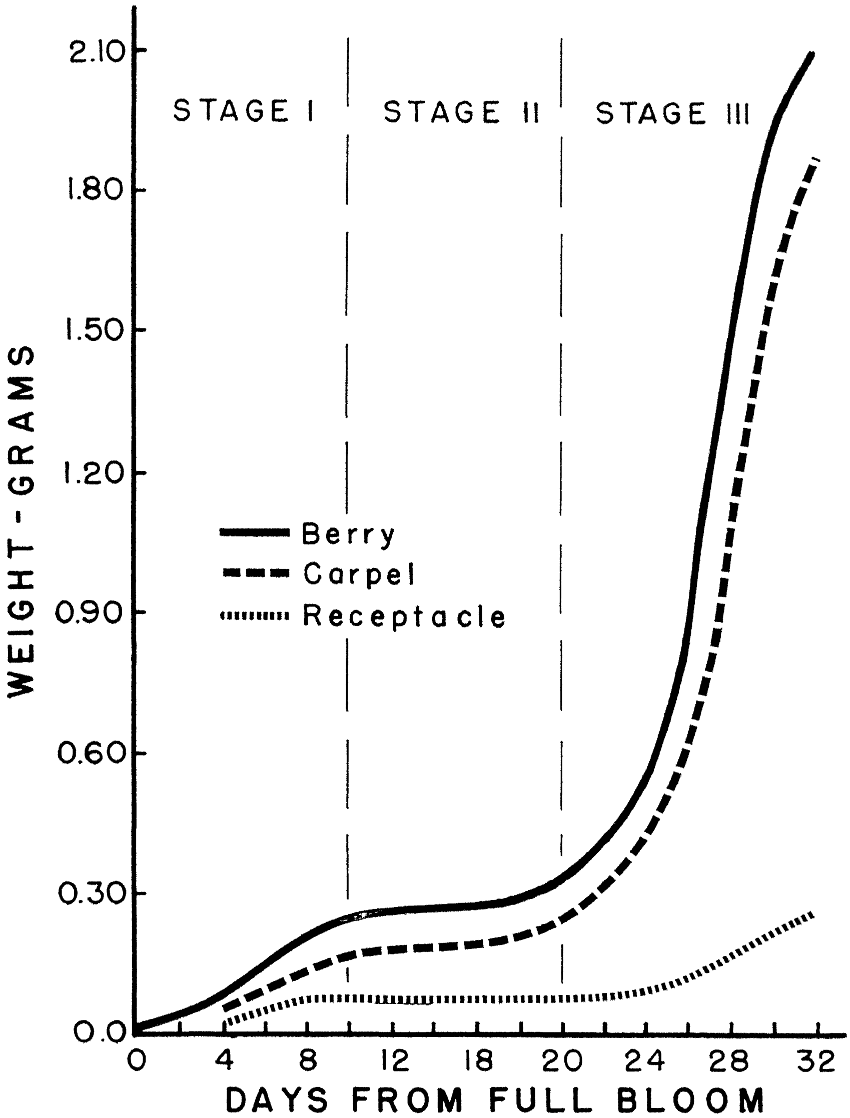

Fig. 3.—Changes in berry, carpel, and receptacle weights recorded at two-day intervals from time of full bloom, June 9, to time of maturity, July 11, of Latham red raspberry fruits. Wooster, Ohio. 1952.

just prior to the time of maturity as was indicated by the pH values Table 1 and Figure 5. At the time of maturity the fruits became slightly less acid. These changes in hydrogen ion content are similar to those

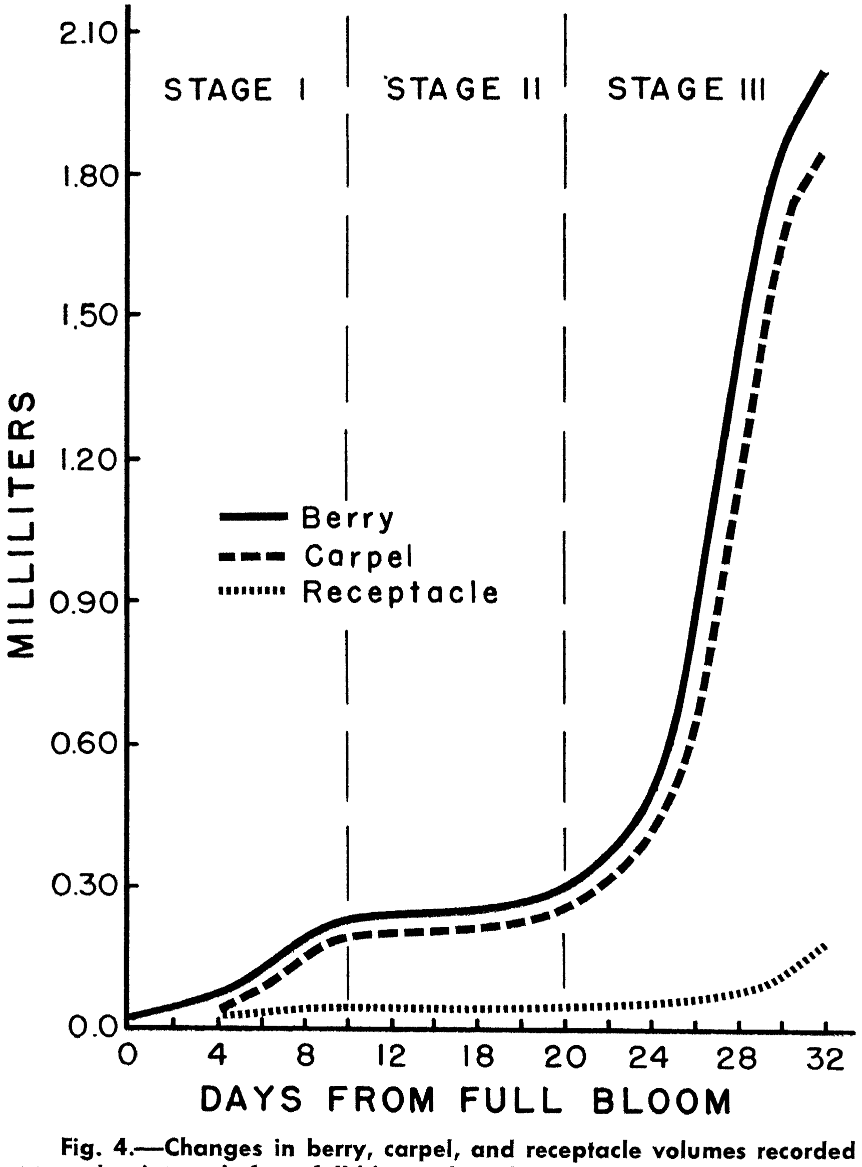

Fig. 4.—Changes in berry, carpel, and receptacle volumes recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberry fruits. Wooster, Ohio. 1952.

that have been reported previously (1) for a number of other fruits. The changes in hydrogen ion concentration were not related to the three stages of growth noted in the morphological development of the berry.

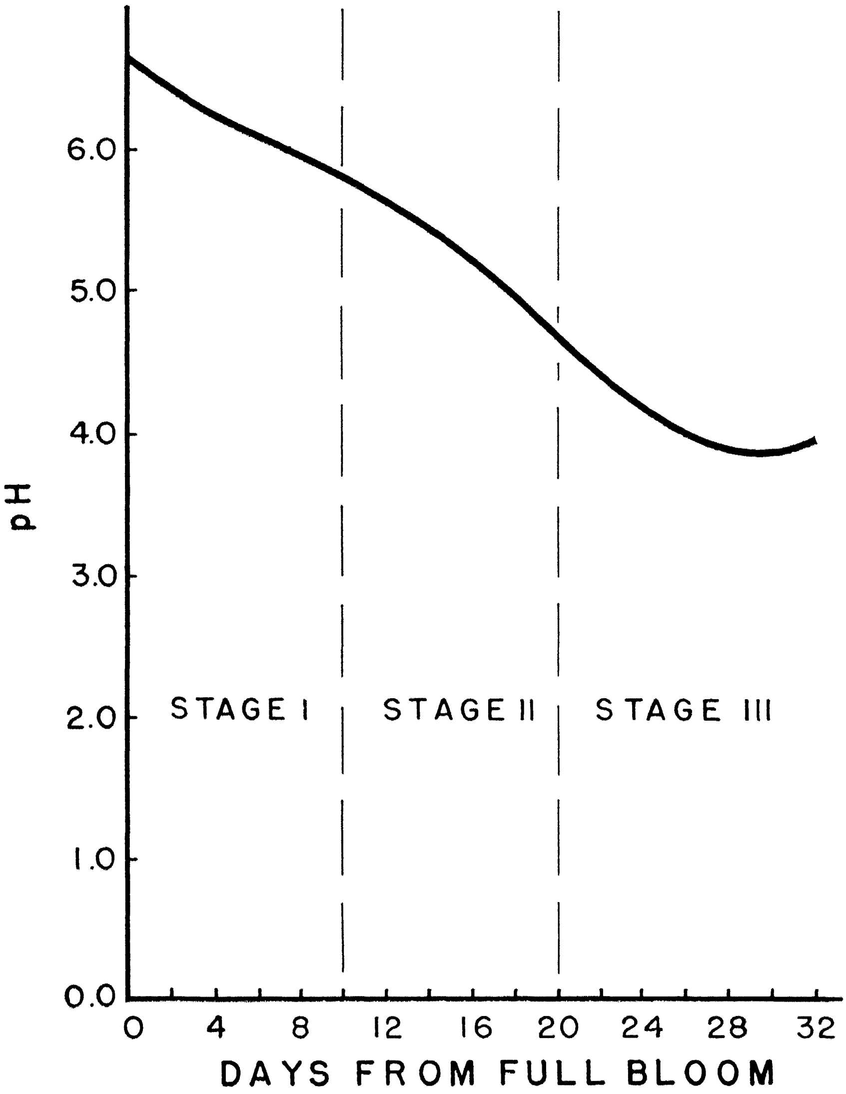

Fig. 5.—Changes in pH of the fruit recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberry fruits. Wooster, Ohio. 1952.

Titratable Acid—The percent titratable acids found, Table 1, Figure 6[1], in the fruits at different stages of development followed the changes in pH already noted. The mean acid content of the fruits was lowest 0.28 percent at the time of full bloom. The percent acid in the fruits then increased in a generally uniform manner until the maximum acid content, 1.42 percent, was reached on the 26th day after full bloom when the berries began to color. The acid content then decreased until, at the time of maturity, the berries contained 0.99 percent acid. The changes in titratable acid were not associated with the growth pattern noted in the morphological development of the berry.

MORPHOLOGICAL DEVELOPMENT OF BERRY PARTS

By the fourth day after full bloom the berries were of sufficient size so that with care they could be separated into carpellary and receptaculary tissues. It was not until the 12th day after full bloom that the individual drupelets of the berries could be separated. At this time the terminal or center drupelet was separated for the determination of drupelet size.

Carpel Weight—The carpel weight data, Table 2, when plotted produced a characteristic sigmoid growth curve, Figure 3. There were three marked stages in the morphological development of these tissues. There was a sharply accelerated growth period, a diminished growth rate during the second phase and a third stage which was a period of very rapid growth. The carpel tissue during the second stage increased in weight only 12.8 percent while during the third stage the weight of these tissues increased 754 percent.

Carpel Volume—The changes in the volume of the carpel tissues during the development of the berry, Table 2, were found to produce a typical sigmoid curve, Figure 4. The same three growth stages were apparent. It is interesting to note the relationship between the percent increase in carpel volume and the percent increase in carpel weight. During the second stage of development the differences were insignificant; th volume increased 13.7 percent while the weight increased 12.8 percent. During the third stage these differences were marked, the volume increasing 694 percent while the weight increased 754 percent.

Receptacle Weight—The development of the receptacle as indicated by changes in weight, Table 2 and Figure 3, was found to be similar to that of the entire berry. It is of interest to note that the

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[1]Curve fitted after the manner of R. L. Anderson and E. E. Houseman. Tables of Orthogonal Polynomial Values Extendent to N:104, Iowa Research Bul. 297. 1942.

TABLE 2.—Changes in the average carpel weight and volume, receptacle weight, volume, polar diameter, and basal diameter of developing Latham red raspberries. Wooster, Ohio, 1952

Days from full bloom	Carpel		Receptacle			
	Weight (gms.)	Volume (ml.)	Weight (gms.)	Volume (ml.)	Basal diameter (mm.)	Polar diameter (mm.)
0	----	----	----	----	--	--
2	----	----	----	----	--	--
4	0.051	0.049	0.033	0 020	--	--
6	0 077	0.078	0.058	0.024	--	--
8	0.155	0.165	0.068	0.036	--	--
10	0.195	0.204	0.065	0.037	--	--
12	0.167	0.204	0.069	0.029	3.2	4.3
14	0.181	0.203	0.065	0.034	3.1	3.9
16	0.232	0.253	0.071	0.040	3.2	4.2
18	0.220	0.232	0.068	0.038	3.1	4.0
20	0.234	0.245	0.082	0.031	3.2	4.2
22	0.313	0.313	0.092	0.059	3.3	4.3
24	0.410	0.409	0.096	0.065	3.7	4.8
26	0.863	0.842	0.133	0.114	4.1	6.0
28	1.161	1.186	0.168	0.088	4.3	6.2
30	1.686	1.719	0.241	0.119	4.7	7.4
32	1.879	1.843	0.259	0.176	5.9	8.8

receptacle weight did not increase on a percentage basis as much during the third phase of development as did the carpel tissues. The carpels increased 754 percent while the receptacle increased only 281 percent.

Receptacle Volume—The growth of the receptacle of the red raspberry fruit as determined by changes in its volume, Table 2 and Figure 4, was found to parellel that of the entire berry as indicated by the various growth indices already discussed. It was again noted that the rate of development of the receptacle was less rapid than was that of the carpel tissues. It will be noted that during Stage III the carpel volume increased 694 percent while the volume of the receptacle tissues increased only 363 percent.

Receptacle Polar Diameter—When the data pertaining to the changes that occurred in the polar diameter of the receptacle during the development of the berry, Table 2 and Figure 7, were considered it was evident that there were marked growth stages in the development of these tissues. Although it was impossible to determine the size of these tissues prior to the 12th day after full bloom, these data indicate that there was a period of eight days, (12th to 20th after full bloom) during which little change in receptacle length occurred. Following that period, from 20 days after full bloom until maturity, rapid elongation had occurred. During this latter period the receptacle increased over 120 percent from 4.0 mm. to 8.8 mm.

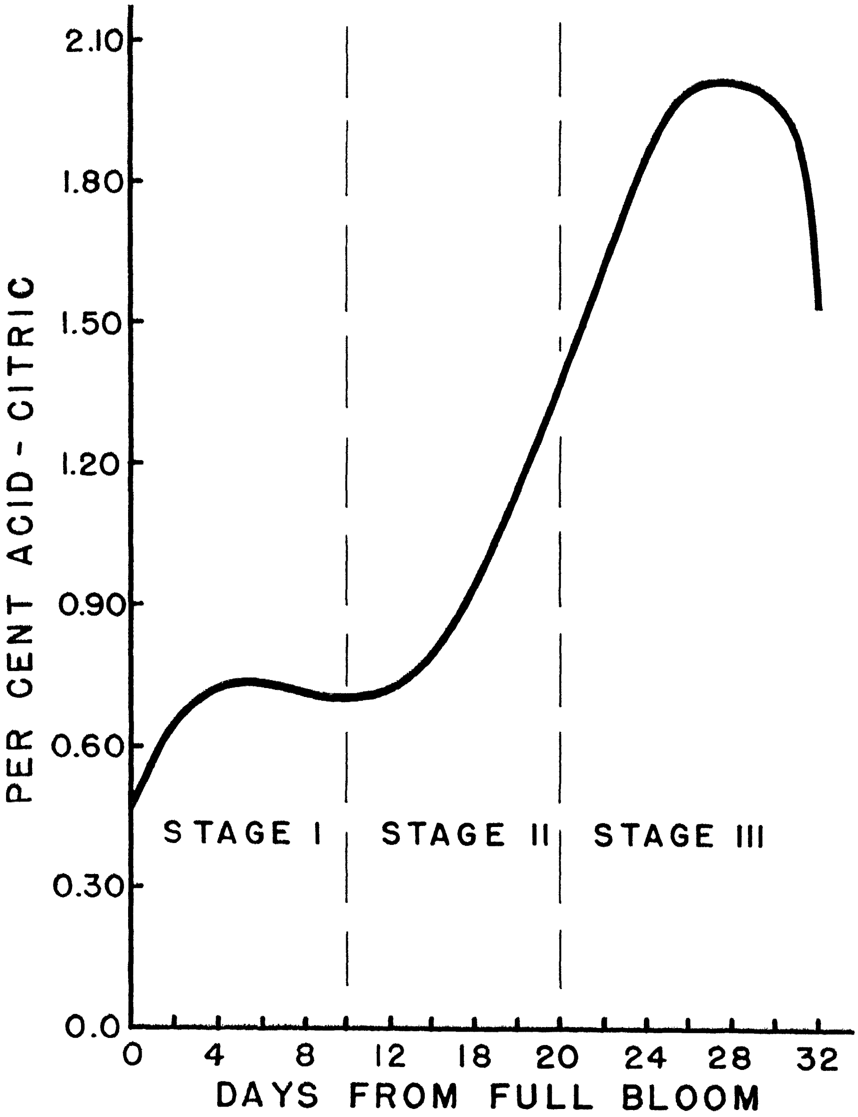

Fig. 6.—Changes in total acid content (as percent citric acid) recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberry fruits. Wooster, Ohio. 1952.

Receptacle Basal Diameter—The data pertaining to the changes in the basal diameter of the receptacle during the development of the berry are presented in Table 2 and Figure 7. These data suggest that the increase in the basal diameter of the receptacle occurred in the manner similar to that of the polar diameter. During Stage III basal diameter of the receptacle increased from 3.1 mm. to 5.9 mm., an increase of 90 percent.

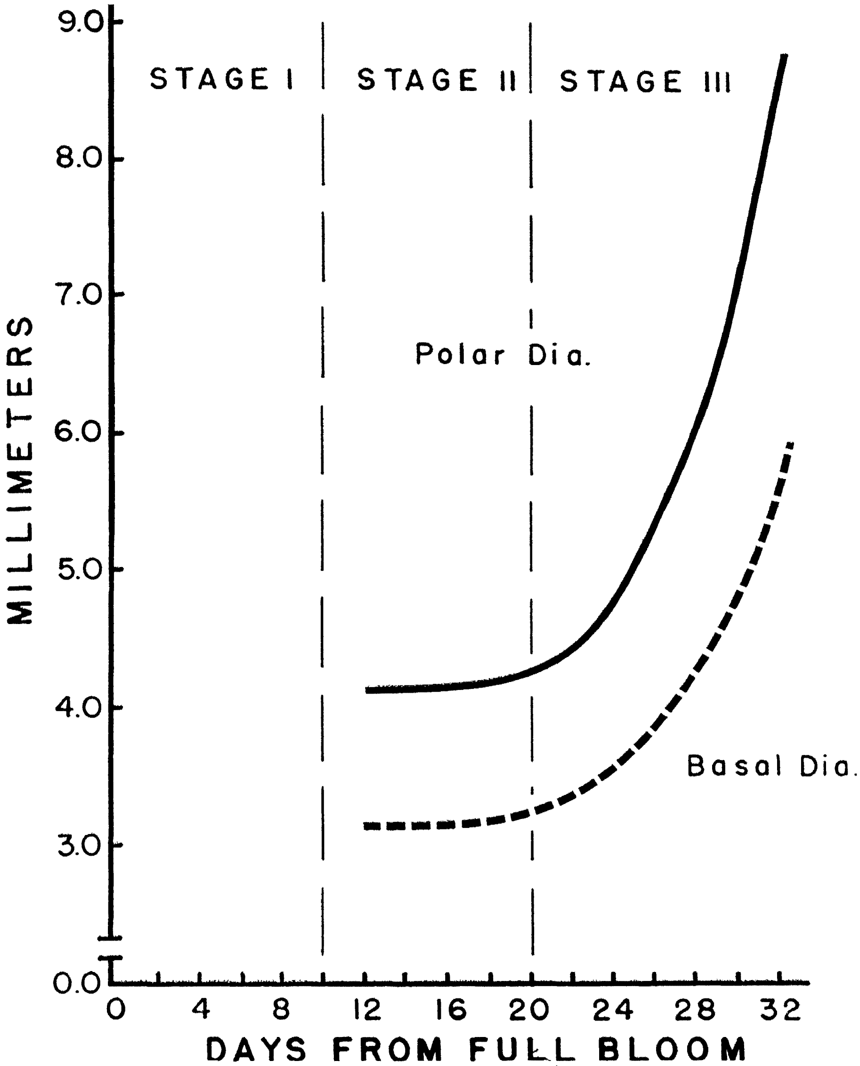

Fig. 7.—Changes in receptacle polar and basal diameters recorded at two-day intervals from full bloom, June 9, to maturity, July 11, of Latham red raspberry fruits. Wooster, Ohio. 1952.

Drupelet Length—The berries had developed sufficiently so that the individual drupelets could be separated on the fourteenth day after full bloom. The data on drupelet length, Table 3, suggest that they increased in length in much the same manner as has been recorded for the drupe fruits. The second stage of development apparently continued through the twentieth day after full bloom. Stage III continued from the twentieth day until maturity. During the third stage until the thirtieth day from full bloom, the mean drupelet length increased 125 percent. It was impossible to measure the size changes of the individual drupelets after the thirtieth day as the drupelets softened with maturity and could not be properly separated.

Drupelet Diameter—The data showing the changes in the diameter of the drupelets, Table 3, indicated again that the drupelets developed in much the same manner as a typical drupe fruit. The data suggest the occurrence of the marked stages of development. Stage II continued through the twentieth day. The final stage of growth continued from the twentieth day until maturity. During the third stage, until the thirtieth day from full bloom, the diameter of the drupelets increased 183 percent.

Drupelet Weight—The changes in weight of the individual drupelets, as indicated by the changes of the terminal drupelet, Table 3, further illustrates the similarity in development between the drupelet and the drupe type fruit. The second stage of development was in evidence

TABLE 3.—Changes in the average weight, polar diameter, and tranverse diameter of individual drupelets of developing Latham red raspberries. Wooster, Ohio, 1952

Days from full bloom	Weight (gms.)	Polar diameter (mm.)	Tranverse diameter (mm.)
12	------	--	--
14	0.0028	2.2	1.2
16	0.0029	2.2	1.2
18	0.0033	2.2	1.2
20	0.0036	2.2	1.3
22	0.0064	2.4	1.8
24	0.0084	2.7	2.1
26	0.0186	3.5	3.1
28	0.0204	3.8	3 1
30	0.0262	4.5	3.4
32	------	--	--

until the twentieth day. From the twentieth day until the last day that the drupelets could be separated, Stage III, there was a rapid increase in weight. During this period the weight increased from 0.0033 to 0.0262 grams, an increase of 694 percent.

Seed Development—The hardening of the seeds within the Latham red raspberry drupelets closely paralleled that recorded for the hardening of seeds within the peach and other drupe fruits. The seeds of the raspberry were found to begin to harden at the conclusion of the Stage I. In the first sampling date during Stage II, tenth day, the majority of the seed were becoming hard. The next sampling date, twelfth day, the seeds had all become hard. At this time the seed coat was such that it could not be readily cut with a sharp scalpel.

EFFECT OF DIFFERENTIAL NITROGEN UPON DEVELOPMENT OF THE BERRY AND BERRY PARTS

The results dealing with the morphological development of the berry were based upon the mean values obtained from berries produced on plants which were maintained without any nitrogen fertilization (0 N) with annual application of fifty pounds of actual nitrogen per acre (50 N), and with annual applications of 100 pounds of actual nitrogen per acre (100 N). The effect of these differential nitrogen treatments upon the development of the berry and berry parts are presented in Tables 4-10.

When the individual basal and polar diameters, Table 4, and weights, Table 5, of the developing berry were compared by a one-way analysis of variance, it was found that on only 4 of the 17 sampling dates were there any statistically significant differences between the mean berry sizes produced by the plants growing under the different nitrogen treatments. When the basal diameter data, Table 4, were considered it was found that the differential nitrogen fertilizer applications had resulted in significant differences in this growth index. This occurred at the time of, four days after, sixteen days after, and thirty days after full bloom. At the time of full bloom the average basal diameter of the berries from the 50 N plants was significantly smaller than those from the 0 N plants, while there was no difference between the polar diameters of berries from the 0 N and 100 N plants or from the 50 N and 100 N plants. On the fourth and sixteenth days, the average basal diameter of the berries produced by the 100 N plants was statistically smaller than that of the berries produced under the other nitrogen levels. On these two sampling dates there was no significant difference noted between the basal diameter of the berries from 0 N and 50 N plants.

TABLE 4.—Changes in the average polar and basal diameters recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	Basal Diameter (mm.)				Polar Diameter (mm.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	3.1	2.9*	3.0	3.0	3.2	3.0	3.1	3.1
2	3.9	4.0	4 0	4.0	3.8	3.9	4.1	3.9
4	5.6	5.4	5.1†	5.4	5.0	4.8	4.8	4.9
6	6.1	5.9	6.1	6.0	5.4	5.1	5.4	5.3
8	8.1	7.9	8.1	8.0	7.1	6.6	6.7	6.8
10	8.5	8.4	8.3	8.4	7.5	7.4	7.2	7.4
12	8.3	8.3	8.2	8.3	7.2	7.2	7.1	7.2
14	8.6	8.2	8.3	8.4	7.5	7.1	7.1	7.2
16	8.7	8.8	8.4*	8.6	7.6	7.9	7.1†	7.5
18	8.7	8.4	8.4	8.5	7.5	7.2	7.2	7.3
20	8.8	8.8	8.5	8.7	7.9	7.6	7.5	7.7
22	9.8	9.4	9.0	9.4	8.8	7.9†	7.9†	8.2
24	10.5	9.9	10.1	10.2	9.4	8.6*	8.6*	8.9
26	13.2	13.0	12.5	12.9	11.3	11.4	11.0	11.2
28	13.8	14.5	13.9	14.1	12.5	13.1	12.6	12.7
30	15.6	16.7*	15.8	16.0	13.9	15.0*	13.7	14.2
32	16.3	16.8	15.9	16.3	14.6	15.0	14.0	14.5

*Significantly different from 0 N value at 5% level.
†Significantly different from 0 N value at 1% level.

The average basal diameter of the berries from the 50 N plants was significantly larger than that of the berries from the 0 N or 100 N plants thirty days after full bloom. At that time there was no significant difference between the berries from the 0 N and 100 N plants in that dimension. Although there were some real and significant differences observed in the basal diameters of the developing berries which could be attributed to differential nitrogen fertilization, these differences appeared to occur at random. Because of this apparent chance occurrence of these differences, it was concluded that differential nitrogen had no consistant effect upon berry development as indicated by changes in basal diameter.

Significant differences in the polar diameters of the developing berries, the result of the differential nitrogen applications, were observed on four sampling dates; sixteen days, twenty-two days, twenty-four days and thirty days after full bloom, Table 4. On the sixteenth day after

TABLE 5.—Changes in the average berry weight and berry volume recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	Berry Weight (gms.)				Berry Volume (ml.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	0.020	0.026†	0.026†	0.024	0.029	0.029	0.029	0.029
2	0.035	0.043*	0.047†	0.042	0.041	0.047	0.041	0.043
4	0.089	0.081	0.081	0.084	0.068	0.068	0.072	0.069
6	0.128	0.113	0.117	0.119	0.106	0.100	0.100	0.102
8	0.240	0.209	0.219	0.223	0.227	0.188	0.188	0.201
10	0.270	0.269	0.229	0.256	0.250	0.256	0.215	0.240
12	0.236	0.224	0.227	0.236	0.230	0.235	0.235	0.233
14	0.269	0.230	0.240	0.246	0.247	0.235	0.229	0.237
16	0.320	0.325	0.266†	0.303	0.306	0.308	0.264	0.293
18	0.310	0.281	0.281	0.291	0.250	0.265	0.274	0.263
20	0.334	0.325	0.290	0.316	0.306	0.280	0.274	0.287
22	0.448	0.381*	0.385*	0.405	0.412	0.353	0.353	0.373
24	0.559	0.459	0.500	0.506	0 529	0.438	0.456	0.473
26	1.081	0.999	0.908	0.996	1.044	0.956	0.868	0.956
28	1.267	1.437	1.184	1.329	1.265	1.324	1.235	1.275
30	1.863	2.047	1.867	1.924	1.735	2.029	1.750	1.838
32	2.108	2.348	1.958	2.138	2.059	2.235	1.764	2.019

*Significantly different from 0 N value at 5% level.
†Significantly different from 0 N value at 1% level.

full bloom the average polar diameter of the berries from the 100 N plants was statistically smaller than those of the berries from the plants which received the 0 N and 50 N treatments. The polar diameter of the berries produced by the 50 N and 100 N plants was found to be significantly smaller than those of the 0 N plants on two sampling dates; twenty-two and twenty-four days after full bloom. There was no difference on these dates between the polar diameters of the berries produced by plants which had received the different nitrogen treatments. Later, thirty days after full bloom, it was found that there was no difference between the polar diameters of the berries produced by the 0 N and 100 N plants, but the polar diameters of berries from plants receiving these two treatments were significantly smaller than those of the berries from the 50 N plants. As was indicated in the case of the basal diameter, there were differences in polar diameters of the developing berries produced by plants under the different nitrogen treatments

Again these differences occurred in such a manner that there appeared to be no overall effect of the nitrogen treatments upon the development of the berry.

The weights of the berries produced by the plants growing under the differential nitrogen treatments, Table 5, were found to be significantly different at the time of full bloom. It was found that at full bloom and two days thereafter berries from the fertilized plants were statistically larger than were those produced by the plants grown without supplemental nitrogen. There was no difference on either occasion in the weight of berries resulting from the different nitrogen applications. There were no other differences in berry weight associated with the different nitrogen levels until the sixteenth day after full bloom at which time berries from the 100 N plants were found to be significantly smaller than those from the 0 N and 50 N plants. On the twenty-second day after full bloom the average weights of the berries produced by the 50 N and 100 N plants were significantly less than those from the

TABLE 6.—Changes in the average receptacle weight and receptacle volume recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates Wooster, Ohio, 1952

Days from full bloom	Receptacle Weight (gms.)				Receptacle Volume (ml.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	----	----	----	----	----	----	----	----
2	----	----	----	----	----	----	----	----
4	0.040	0.033	0.026	0.033	0.021	0.021	0.019	0.020
6	0.043	0.037	0.094	0.058	0.024	0.025	0.024	0.024
8	0.064	0.065	0.075	0.068	0.040	0.032	0.035	0.036
10	0.069	0.057	0.070	0.065	0.038	0.045	0.027	0.037
12	0.073	0.069	0.065	0.069	0.027	0.029	0.032	0.029
14	0.063	0.062	0.071	0.065	0.041	0.029	0.032	0.034
16	0.075	0.076	0.061*	0.071	0.041	0.043	0.035	0.040
18	0.063	0.062	0.080	0.068	0.041	0.030	0.045	0.038
20	0.082	0.065	0.099	0 082	0.041	0.045	0.039	0.031
22	0.093	0.089*	0.093	0 092	0.060	0.059	0.059	0.059
24	0.095	0.099	0.094	0 096	0.073	0.063	0.059	0.065
26	0.156	0.123	0.120	0.133	0.103	0.134	0.104	0.114
28	0.147	0.158	0.199	0.168	0.088	0.089	0.088	0.088
30	0.258	0.215	0.249	0.241	0.177	0.147	0.094	0.119
32	0.260	0.207	0.311	0.259	0.206	0.176	0.146	0.176

*Significantly different from 0 N value at 5% level.

0 N plants. Again there was no difference in weight of berries produced under the different nitrogen levels. The differences in weight of the developing berries, which could be associated with different nitrogen fertilizer treatments, like the differences in polar and basal diameter, appeared to occur at random. It was, therefore, concluded that, at the levels considered in this study, nitrogen applications to the plants had no effect upon the development of the berry.

Similar analyses of the differences in weight, basal diameter, and polar diameter of the receptacle showed that on two of the ten dates in the case of the receptacle weight, Table 6, on four of the ten dates in the case of the polar diameter, Table 7, and on three of the ten dates in the case of basal diameter, Table 7, there were significant differences in size associated with nitrogen treatment. These differences also appeared to occur at random indicating no consistant effect of nitrogen fertilization upon the developing receptacle of the berry as indicated by the growth indices considered.

TABLE 7.—Changes in the average polar and basal diameters of the receptacles recorded at two-day intervals from full bloom, June 9, to maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	Basal Diameter (mm.)				Polar Diameter (mm.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--
12	3.1	3.2	3.3	3.2	4.2	4.4	4.2	4.3
14	3.0	3.3	3.0	3.1	3.0	4.2	3.7	3.9
16	3.2	3.5	3.0	3.2	4.5	4.2	3.8*	4.2
18	3.3	3.0*	2.9†	3.1	4.2	4.0	3.8	4.0
20	3.3	3.2	3.1	3.2	4.5	4.1†	4.0†	4.2
22	3.4	3.2*	3.3	3.3	4.6	4.1	4.3	4.3
24	3.8	3.6	3.6	3.7	5.2	4.5	4.7	4.8
26	4.3	4.1	3.8	4.1	6.1	6.1	5.7	6.0
28	4.3	4.4	4.2	4.3	6.6	6.3	5.8	6.2
30	4.5	5.0†	4.6	4.7	7.5	7.5	7.2	7.4
32	6.0	5.9	5.7	5.9	9.1	8.7	8.6	8.8

*Significantly different from 0 N value at 5% level.
†Significantly different from 0 N value at 1% level

Similarly, when the data showing the changes in polar and transverse diameter of developing drupelets of berries from plants growing under the different nitrogen treatments, Table 8, were examined statistically, no consistant differences due to treatment were noted. On the sixteenth day after full bloom it was found that the drupelets of the berries from the nitrogen fertilized plants were statistically smaller in polar diameter than those which were produced without supplemental nitrogen. In no other instance was there a significant difference in polar diameter of the drupelet associated with nitrogen treatment noted. In only one instance was there a difference in the transverse diameter of the drupelet noted that could be associated with the difference in nitrogen treatment. That difference was noted on the twentieth day after full bloom when the drupelets from the non-fertilized plants were significantly larger than those of berries produced by the 50 N and 100 N fertilized plants. It was impossible to determine statistically the effect

TABLE 8.—Changes in the average polar and transverse diameters of the drupelet recorded at two-day intervals from full bloom, June 9, to maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	Polar Diameter (mm.)				Transverse Diameter (mm.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--
8	--	--	--	--	--	--	--	--
10	--	--	--	--	--	--	--	--
12	--	--	--	--	--	--	--	--
14	2.2	2.2	2.2	2.2	1.2	1.3	1.2	1.2
16	2.3	2.2*	2.1†	2.2	1.2	1.2	1.2	1.2
18	2.2	2.3	2.2	2.2	1.2	1.3	1.2	1.2
20	2.2	2.2	2.1	2.2	1.4	1.2†	1.2†	1.3
22	2.5	2.3	2.5	2.4	1.7	1.7	1.9	1.8
24	2.7	2.6	2.7	2.7	2.2	1.9	2.1	2.1
26	3.5	3.6	3.5	3.5	3.1	3.1	3.0	3.1
28	3.8	3.9	3.8	3.8	3.0	3.1	3.1	3.1
30	4.4	4.6	4.4	4.5	3.5	3.5	3.3	3.4
32	--	--	--	--	--	--	--	--

*Significantly different from 0 N value at 5% level.
†Significantly different from 0 N value at 1% level.

Table 9.—Changes in the average carpel weight and carpel volume recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	Carpel Weight (gms.)				Carpel Volume (ml.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	----	----	----	----	----	----	----	----
2	----	----	----	----	----	----	----	----
4	0.049	0.048	0 055	0.051	0.047	0.047	0.053	0.049
6	0.085	0.070	0.076	0.077	0.082	0.075	0.076	0.078
8	0.176	0.144	0.144	0.155	0.187	0.156	0.153	0.165
10	0.201	0.212	0.171	0.195	0.212	0.211	0.188	0.204
12	0.163	0.175	0.162	0.167	0 203	0.206	0.203	0.204
14	0.206	0.168	0.169	0.181	0.206	0.206	0.197	0 203
16	0.245	0.249	0.201	0.232	0 265	0.265	0.229	0.253
18	0.247	0.219	0.195	0.220	----	0.235	0.229	0.232
20	0.252	0.245	0.206	0.234	0.265	0.235	0.235	0.245
22	0.355	0.292	0.292	0.313	0.352	0.294	0.294	0.313
24	0.463	0.360	0 406	0.410	0.456	0.375	0.397	0.409
26	0.925	0 877	0.848	0.863	0.941	0.822	0.764	0.842
28	1.120	1.279	1.423	1.161	1.177	1.235	1.147	1.186
30	1.606	1.891	1.622	1 686	1.618	1.882	1.656	1.719
32	1.848	2.141	1.647	1 879	1.853	2.059	1.618	1.843

of the differential nitrogen treatments upon the following developmental indices as these data were obtained on a composite sample basis rather than on the individual berry basis: total berry volume, carpel volume, receptacle volume, carpel weight, and drupelet weight. These data, Tables 5, 6, 9, and 10, do not appear, however, to indicate any specific effect of the differential nitrogen levels upon the development of the berry.

When the data concerned with the pH and acid changes within the developing fruits, Table 11, were analyzed by an analysis of variance, the results indicated that there were no significant differences in these values associated with the different nitrogen treatments. Thus, it appears that differential nitrogen, at the levels considered, had no effect upon these changes during the development of the berry.

It should be noted that the berries produced under the different nitrogen levels matured at the same time. There was no apparent delay in maturity as a result of increasing the rate of nitrogen fertilization.

TABLE 10.—Changes in the average drupelet weight recorded at two-day intervals from full bloom, June 9, to maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	Drupelet Weight (gms.)			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	------	------	------	------
2	------	------	------	------
4	------	------	------	------
6	------	------	------	------
8	------	------	------	------
10	------	------	------	------
12	------	------	------	------
14	0.0024	0.0031	0.0029	0.0028
16	0.0028	0.0031	0.0029	0.0029
18	0.0038	0.0032	0.0039	0.0033
20	0.0038	0.0027	0.0044	0.0036
22	0.0071	0.0050	0.0071	0.0064
24	0.0094	0.0069	0.0088	0.0084
26	0.0171	0.0200	0.0188	0.0186
28	0.0191	0.0225	0.0197	0.0204
30	0.0275	0.0260	0.0250	0.0262
32	------	------	------	------

RELATIONSHIP OF THE RECEPTACULAR AND CARPELLARY TISSUES IN BERRY DEVELOPMENT

To establish the relationship of the developing receptacular and carpellary tissues in the development of the entire berry the ratios of the mean berry weight to the mean receptacle weight, the mean berry weight to the mean carpel weight, the mean berry volume to the mean receptacle volume, and the mean berry volume to the mean carpel volume were calculated for each harvest date from the fourth day after full bloom until maturity. These comparisons are presented in Table 12.

It was found that on the fourth day after full bloom the receptacular tissues accounted for a relatively large proportion of the total weight and volume of the developing berry. As Stage I progressed that proportion of the weight and volume of the berry contributed by the receptacular tissue diminished. There were some variations in the relationship of the weight and volume of the receptacular tissues to that of

TABLE 11.—The changes in the average pH and total acid content (as % citric acid) recorded at two-day intervals from full bloom, June 9, to time of maturity, July 11, of Latham red raspberries fertilized with nitrogen at different rates. Wooster, Ohio, 1952

Days from full bloom	pH Values				Percent Acid Content			
	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean*	0 lbs. N/acre	50 lbs. N/acre	100 lbs. N/acre	Mean
0	6.05	6.27	6.20	6.17	0.41	0.17	0.27	0.28
2	5.75	5.75	5.65	5.71	0.45	0.46	0.39	0.43
4	5.80	6.00	5.70	5.82	0.42	0.40	0.61	0.48
6	5.70	5.70	5.70	5.70	0.46	0.56	0.60	0.54
8	5.70	5.65	5.70	5.68	0.37	0.37	0.35	0.36
10	5.25	5.25	5.30	5.25	0.38	0.54	0.52	0.48
12	5.00	4.95	5.00	4.99	0.48	0.48	0.49	0.48
14	4.80	4.78	4.80	4.79	0.52	0.61	0.58	0.57
16	4.65	4.50	4.60	4.59	0.63	0.71	0.77	0.70
18	4.45	4.55	4.55	4.51	0.78	0.67	0.68	0.71
20	4.50	4.55	4.55	4.53	0.73	0.66	0.66	0.68
22	4.10	4.10	4.10	4.10	1.10	1.08	1.16	1.11
24	3.60	3.75	3.75	3.69	1.39	1.28	1.39	1.35
26	3.30	3.50	3.30	3.36	1.34	1.55	1.36	1.42
28	3.20	3.25	3.25	3.23	1.33	1.15	1.51	1.33
30	3.30	4.00	3.45	3.50	1.09	1.09	1.00	1.06
32	3.40	3.55	3.55	3.50	1.17	0.79	1.01	0.99

*Obtained by converting pH values to Hydrogen ion values, determining the mean and converting back to pH.

the entire berry during the second growth stage. In general, however, during Stage II the relative proportion of the entire berry which was receptacle remained fairly constant. There were marked changes in these relationships during Stage III when the weight and volume of the entire berry and of the receptacle were increasing rapidly. During this phase of development the ratio of the mean berry weight to the mean receptacle weight and the ratio of the mean berry volume to the mean receptacle volume at each sampling date became progressively larger. This situation indicates that as the berry grew toward final size the receptacular tissue accounted for a progressively smaller proportion of the fruit. Thus the receptacle growth rate was less than that of other parts of the berry. This situation is illustrated by the ratio of the mean berry weight to the mean receptacle weight. At the beginning of Stage III this ratio was 3.85, while at maturity it had increased to 8.25.

TABLE 12.—Relationship of the receptacular and carpellary tissues of the Latham red raspberry during its development from time of full bloom, June 9, to maturity, July 11, Wooster, Ohio, 1952

Days from full bloom	Ratio berry weight to receptacle weight	Ratio berry weight to carpel weight	Ratio berry volume to receptacle volume	Ratio berry volume to carpel volume
0	----	----	----	----
2	----	----	----	----
4	2 55	1.65	3 45	1 41
6	3.43	1.55	4.25	1 31
8	3 28	1.44	5.58	1.22
10	2 94	1.31	6 49	1.18
12	3 42	1.41	8.03	1 14
14	3.78	1.36	6 97	1.17
16	4.27	1.31	7.33	1.16
18	4.28	1.32	6.92	1.13
20	3.85	1.35	7.90	1.17
22	4.40	1.29	6.32	1.19
24	5.27	1.23	7.28	1.16
26	7.49	1.15	8.39	1.14
28	7.91	1.14	14.49	1.08
30	7.98	1.14	15.45	1.07
32	8.25	1.14	11.47	1.10

This data, Table 12, indicated the relative importance of the carpellary tissue to the entire berry during all stages of development. When the ratios of the mean berry weight to the mean carpel weight and the ratio of the mean berry volume to the mean carpel volume were examined, it was found that these ratios diminished slightly during Stage I. There were no marked changes in either of the two ratios during the second growth phase, while during the final phase of development both ratios again diminished slightly. During the entire period of development the ratios remained near unity, indicating that throughout the development of these aggregate fruits the carpellary tissues predominated.

THE EFFECT OF NITROGEN APPLICATION UPON THE PLANTS

The plants from which the berries in these studies were obtained reflected the differential nitrogen treatment. The results of a chemical analysis of the leaves, Table 13, showed that the nitrogen level within the plants was increased slightly by the differential treatment. These

TABLE 13.—Effect of three different nitrogen application rates upon the Latham red raspberry as indicated by leaf area, leaf color, and leaf nitrogen content. Wooster, Ohio, 1952

	Pounds of Nitrogen per Acre		
	0	50	100
Percent total nitrogen	2.67	2.82	2.96
Relative leaf color*	42.5	42.2	41.0
Leaf area, square centimeter	33.5	36.3	35 1

*The lower the value, the darker green the leaf.

analysis showed that the nitrogen content of the plants which received the 50 N and 100 N treatment contained 5.6 and 10.9 percent more nitrogen respectively than did those which were not fertilized.

The response of the plants to the differential nitrogen treatment was also shown in the leaf color and leaf area data, Table 13. These data indicate that the nitrogen treatments caused an increase in the leaf color and in leaf area. In the case of leaf area the percent increase was 4.4 and 8.1 respectively for the 50 N and 100 N treatments.

It should be noted that the plants of the 0 N plots which received no nitrogen fertilizer during the spring of 1952 nor during the two previous seasons, were not nitrogen deficient. These plants exhibited no deficiency symptoms and the leaf nitrogen level was well above 2.40 percent of the dry weight, the tentative critical level for raspberries proposed by Hill and Heeney (3).

THE GROWING SEASON

The season in which this study was conducted was abnormally dry. Rainfall for the month of June was 3.04 inches below the 69 year average for the month. From the time of full bloom until maturity the planting received 2.16 inches of rain. Of this amount 0.81 inches fell on the 24th day and 0.42 came on the 29th day.

DISCUSSION

The development of the aggregate fruit of the Latham red raspberry was found to be similar to that of a number of other fruits, particularly those of the drupe class. Although these aggregate fruits are so strikingly different in structure from the drupe fruits that they have been separated in botanical classification, they exhibited the same three marked growth stages reported (2, 4, 5, 6, 7, & 8) for drupeacous fruits.

The first phase, Stage I, which commenced at the time of full bloom and continued for ten days was one of rapid development. Stage II which continued from the tenth till the twentieth day after full bloom was characterized as a period of limited growth. The final phase, Stage III, which extended from the twentieth day after full bloom until the time of maturity, was a period of rapid growth. As in the case of a number of other fruits these three growth periods were evidenced when any of a number of growth indices were considered.

There may be several explanations for the similarity of the growth curves of these developing aggregate fruits and those of developing drupe fruits. The most logical explanation of this situation, however, appears when these fruits are examined on the basis of their botanical classification. The drupe fruit is defined as one which develops entirely from a single ovary. The aggregate fruit is defined as one which is formed by the ripening together of a number of ovaries, all belonging to a single flower and adhering as a group to a common receptacle. In the case of the raspberry, these ovaries are commonly termed drupelets (10) because of the structural similarity between them and the fruit of the true drupe. These drupelets were found to account for the major portion of the entire berry. When the ratio of the weight of the entire berry to the weight of the carpels or drupelets and the ratio of the volume of the entire berry to the volume of the carpels or drupelets were determined it was found that they ranged near unity. When the weight ratios for the growth period were compared it was found that they ranged from 1.14-1.65, while the volume ratios ranged from 1.07-1.41. These values indicate that throughout the entire developmental period the carpels or drupelets accounted for the majority of the berry and that the growth of the berry was predominated by the growth of these structures. This would appear to be a reason for the similarity of the growth curves of the red raspberry fruit and fruits of the drupe class.

The results of these studies have presented additional evidence to support the use of the term drupelet for the individual carpels clustered about the common receptacle of this aggregate fruit. The data indicating the changes in the weight and the polar and transverse diameters of these drupelets during their development, showed quite clearly the existence of a Stage II and Stage III. Thus these drupelets were found to develop in a manner quite similar to that of a true drupe. These growth stages of the drupelet were found to correspond to the same growth stages of the entire berry. Thus, although it was impossible to obtain definite proof in this study of the existence of Stage I in the development of these structures, it is possible by inference to state that they passed through such a stage.

Further proof of a similarity of the drupelet and the true drupe is obtained if time of hardening of the seed or endocarp of the two structures is compared. In this study it was found that the hardening of the endocarp of the drupelets occurred during Stage II. In the development of the true drupe fruit the hardening of the pit or endocarp also occurs during Stage II. The similarity of endocarp of the true drupe and that of these drupelets has been shown by anatomical study (11).

An interesting fact concerning the development of the red raspberry fruit is that these berries developed more in basal diameter than in polar diameter, while the receptacle within the fruit developed more in polar diameter than in basal diameter. These facts appear opposed. They can be reconciled, however, if one considers that the individual drupelets are attached to the receptacle in such a way that the long axis of the drupelet is roughly perpendicular to the point where it adjoins the receptacle. Thus growth in polar diameter of the entire berry equals the growth in polar diameter of the receptacle plus the growth in polar diameter of a single drupelet. The growth of the entire berry in basal diameter then equals the growth in basal diameter of receptacle plus the growth in polar diameter of two drupelets. Hence, the apparent difference in growth of the two diameters. It will be noted that final berry sizes cannot be accurately obtained by adding the mean receptacle diameters and mean polar diameters of the terminal drupelet. This variation can only be attributed to variations in drupelet sizes that undoubtedly occur over the surface of the berry.

The relationship of the berry volume to the berry weight in the development of the berry should be considered. As the berry developed it made greater gains in weight than in volume. This situation is considered to be indicative of the deposition of the products of photosynthesis in the various tissues of the berry. It is also indicative of the fact that has long been known, that growth of fruits is more than a simple swelling of the tissues by the absorption of water. It would be of interest to determine the relative amounts of the various carbohydrate materials involved in these weight changes.

The changes in hydrogen ion concentration and titratable acid content in the developing red raspberry fruit were found to be much like those in the cherry and a number of other fruits (1). The fact that titratable acid content and hydrogen ion content reached a maximum about the time visible pigmentation occurred and then decreased as ripening proceeded was of special interest. These changes are considered to account partially for the increase in palatability of these berries from the time that pigmentation begins to maturity.

The hypothesis proposed by Caldwell (1), "namely, that variations in water absorption by the hydrophilic colloids of the young fruits caused by changes in hydrion concentrations of the tissue fluids, may be a factor of prime importance in determining the form and slope of the growth curve of the fruit," is supported by this study. A correlation coefficient that was calculated between the hydrogen ion concentration and the volume of these berries for the seventeen sampling dates showed that these factors were correlated to a highly significant degree. The R value obtained was $+ .802$ while that required for significance at the one percent level is $+ .606$. This indicates that there undoubtedly is a relationship between the changes in the hydrogen ion concentration within the developing fruit and growth of that fruit. This, of course, does not offer direct evidence that the changes in hydrogen ion concentration has an effect upon water absorption by the hydrophilic colloids, as suggested by the hypothesis. The relationship of the changes in hydrogen ion concentration to the changes in volume of the berry may, however, be considered as circumstantial evidence to support this theory.

Of particular interest is the relationship of the differential nitrogen treatments and the development of the berry. In this study it was found that the growth curves of the berries produced by plants receiving no nitrogen, 50 pounds of nitrogen per acre and 100 pounds of nitrogen per acre were substantially the same. It was also found that the time of ripening of the berries from the various treatments was the same. Yet, the foliar analysis of these plants indicate that the differential nitrogen treatments were reflected by the nitrogen level within the plant.

These results are contrary to those of a study (7) with the peach in which it was noted that an application of nitrogen fertilizer not only altered the growth curve but also delayed maturity. This discrepancy is not considered to be the result of differences in the plant material, but rather in the relative quantities of nitrogen applied in the two studies. Where an effect of nitrogen fertilization upon the development and time of maturity of the peach was noted, nearly five times the usual rate of nitrogen fertilizer was applied to the treated tree and no nitrogen was applied to the non-treated tree. In this study the rates of nitrogen applied to the treated plants were within the bounds of recommended nitrogen fertilizer rates. Perhaps if excessive nitrogen had been applied or if the nitrogen level of the plants which received no nitrogen had been lower, an effect of the nitrogen application upon time of ripening and development of the berry would have been noted.

The relationship of the nitrogen treatments used in this study to the development of the berry and its time of maturity is of importance to the horticulturist and the red raspberry grower alike. It appears that they can safely apply nitrogen fertilizers to red raspberries within the range of recommended rates to foster plant growth and yield without materially affecting the morphological development or the time of maturity of the berry.

Also of special interest to the red raspberry grower is the time of initiation of the final growth phase, "final swell" of the individual berries. This knowledge should aid him in obtaining maximum berry size and hence maximum yields. There are undoubtedly a number of environmental factors that influence the development of these berries during this growth period. One of the most important of these is that of available soil moisture. If a grower expects to obtain maximum berry size he must insure that ample soil moisture will be available during this critical phase in the development of the crop. The results of this study indicate if he is to obtain maximum benefits from any special soil management practices designed to conserve soil moisture or from supplemental irrigation these practices must be initiated at least twelve days before the first picking or twenty days after first bloom. Further, as the raspberry bloom and harvest seasons extend over a two or three week period, these practices should be continued throughout the harvest season in order that they may have the greatest possible effect.

SUMMARY AND CONCLUSIONS

A study was conducted at Wooster, Ohio during the 1952 season to ascertain the morphological and chemical changes that occur during the development of the fruit of the red raspberry and the effect of differential nitrogen fertilization upon these changes. The results of these studies warrant the following conclusions.

1. The entire berry and the different component parts of the berry, carpels, receptacle and drupelet all developed in a similar manner. There were three definite stages of growth. Beginning at the time of full bloom there was a period of rapid growth. This period was followed by one of reduced growth rates during which the endocarp hardens. The third stage which continued to maturity was one of rapid growth.

2. The majority of the growth of the developing fruits was accounted for by the carpellary tissue. The berries grew more in basal than polar diameter and during development they increased proportionally more in weight than in volume.

3. Differential nitrogen fertilization at the levels used in this study had no marked effect upon the development of the berry or upon its time of maturity.

4. The hydrogen ion concentration and the titratible acid contents of the developing berry was lowest at the time of full bloom then increased uniformly until the time that ripening processes started as indicated by pigmentation of the berries and then decreased as ripening progressed.

5. The similarity between the development of the aggregate raspberry fruit and that of the various drupe fruits was demonstrated. Evidence to support the use of the term drupelet for the individaul developing ovaries is presented.

6. The application of nitrogen fertilizer within the limits of current recommendations had no effect upon the development of the raspberry fruit.

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